Optimism is associated with exceptional longevity in 2 epidemiologic cohorts of men and women

Lewina O. Lee[a,b,1], Peter James[c], Emily S. Zevon[d], Eric S. Kim[d,e], Claudia Trudel-Fitzgerald[d,e], Avron Spiro III[b,f,g], Francine Grodstein[h,i,2], and Laura D. Kubzansky[d,e,2]

[a]National Center for Posttraumatic Stress Disorder, Veterans Affairs Boston Healthcare System, Boston, MA 02130; [b]Department of Psychiatry, Boston University School of Medicine, Boston, MA 02118; [c]Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, MA 02215; [d]Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health, Boston, MA 02115; [e]Lee Kum Sheung Center for Health and Happiness, Harvard T.H. Chan School of Public Health, Boston, MA 02115; [f]Massachusetts Veterans Epidemiology Research and Information Center, Veterans Affairs Boston Healthcare System, Boston, MA 02130; [g]Department of Epidemiology, Boston University School of Public Health, Boston, MA 02118; [h]Department of Epidemiology, Harvard T.H. Chan School of Public Health, Boston, MA 02115; and [i]Channing Division of Network Medicine, Brigham and Women's Hospital, Boston, MA 02115

Edited by Bruce S. McEwen, The Rockefeller University, New York, NY, and approved July 30, 2019 (received for review January 18, 2019)

Most research on exceptional longevity has investigated biomedical factors associated with survival, but recent work suggests nonbiological factors are also important. Thus, we tested whether higher optimism was associated with longer life span and greater likelihood of exceptional longevity. Data are from 2 cohorts, women from the Nurses' Health Study (NHS) and men from the Veterans Affairs Normative Aging Study (NAS), with follow-up of 10 y (2004 to 2014) and 30 y (1986 to 2016), respectively. Optimism was assessed using the Life Orientation Test–Revised in NHS and the Revised Optimism–Pessimism Scale from the Minnesota Multiphasic Personality Inventory-2 in NAS. Exceptional longevity was defined as survival to age 85 or older. Primary analyses used accelerated failure time models to assess differences in life span associated with optimism; models adjusted for demographic confounders and health conditions, and subsequently considered the role of health behaviors. Further analyses used logistic regression to evaluate the likelihood of exceptional longevity. In both sexes, we found a dose-dependent association of higher optimism levels at baseline with increased longevity (P trend < 0.01). For example, adjusting for demographics and health conditions, women in the highest versus lowest optimism quartile had 14.9% (95% confidence interval, 11.9 to 18.0) longer life span. Findings were similar in men. Participants with highest versus lowest optimism levels had 1.5 (women) and 1.7 (men) greater odds of surviving to age 85; these relationships were maintained after adjusting for health behaviors. Given work indicating optimism is modifiable, these findings suggest optimism may provide a valuable target to test for strategies to promote longevity.

optimism | longevity | aging | psychological well-being | longitudinal study

As life span has increased in industrialized countries, exceptional longevity—commonly defined as survival to 85 y (1)—has become less rare. Research across diverse organisms consistently demonstrates that increases in life span are often accompanied by delayed morbidity (2). Therefore, factors that promote exceptional longevity are highly relevant to public health as they may extend the duration of good health (also known as "health span"; ref. 3). Research on exceptional longevity has largely focused on identifying biomedical factors (e.g., genetic variants) associated with increased survival, but emerging evidence suggests nongenetic factors also contribute. Recent epidemiologic studies have identified psychosocial assets such as optimism as potential predictors of longer life, based on findings linking higher optimism to reduced risk of developing chronic diseases of aging and premature mortality (4–10).

Importantly, psychosocial assets are associated with health outcomes above and beyond their role in signaling the absence of poor psychosocial functioning (11), such as depression (4), and independent of sociodemographic confounders, health conditions, and health behaviors (12, 13). Identifying diverse positive assets that promote health across the life course, particularly in aging, could contribute to optimal functioning and improved health. Among psychosocial factors that appear to be potential health assets (e.g., social integration; ref. 14), optimism has some of the strongest and most consistent associations with a wide range of health outcomes, including reduced risk of cardiovascular events, lung function decline, and premature mortality (4–10), and associations that are independent of other psychosocial factors such as depression, anxiety, or anger (12). Investigators have speculated that optimism may facilitate healthier biobehavioral processes, and ultimately longevity, because optimism directly contributes to how goals are translated into behaviors (15). Optimism is ∼25% heritable but is also shaped by social structural factors and can be learned, as demonstrated in experimental research (e.g., refs. 16 and 17).

Higher levels of optimism have been linked to reduced risk of premature mortality (4); however, researchers have not considered the association between optimism and achievement of exceptional longevity (18–20). Although no standard definition for exceptional longevity has been established, it has been defined as surviving to older age, and age 85 is a commonly used cutoff (1, 21) as it is well beyond the average life expectancy of individuals born

Significance

Optimism is a psychological attribute characterized as the general expectation that good things will happen, or the belief that the future will be favorable because one can control important outcomes. Previous studies reported that more optimistic individuals are less likely to suffer from chronic diseases and die prematurely. Our results further suggest that optimism is specifically related to 11 to 15% longer life span, on average, and to greater odds of achieving "exceptional longevity," that is, living to the age of 85 or beyond. These relations were independent of socioeconomic status, health conditions, depression, social integration, and health behaviors (e.g., smoking, diet, and alcohol use). Overall, findings suggest optimism may be an important psychosocial resource for extending life span in older adults.

Author contributions: F.G. and L.D.K. designed research; L.O.L., P.J., E.S.Z., E.S.K., and C.T.-F. performed research; L.O.L., P.J., and E.S.Z. analyzed data; and L.O.L., P.J., E.S.Z., E.S.K., C.T.-F., A.S., F.G., and L.D.K. wrote the paper.

Conflict of interest statement: E.S.K. has worked as a consultant with AARP and United Health Group.

This article is a PNAS Direct Submission.

[1]To whom correspondence may be addressed. Email: lewina@bu.edu.

[2]F.G. and L.D.K. contributed equally to this work.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1900712116/-/DCSupplemental.

Published online August 26, 2019.

in the early 20th century, but not extremely rare. Using data from 2 long-running observational cohorts composed of men or women, we evaluated the hypothesis that higher optimism is associated with longer life span and a greater likelihood of achieving exceptional longevity. We considered associations in men and women, and accounted for potential confounders identified in prior work, including other psychosocial factors, baseline health conditions, and health behaviors (4, 6).

Results

We conducted analyses among 69,744 women from the Nurses' Health Study (NHS) and 1,429 men from the Veterans Affairs (VA) Normative Aging Study (NAS). NHS women have been followed since 1976 with biennial questionnaires; they completed an optimism assessment in 2004 and mortality status was tracked until 2014. NAS men have been followed starting in 1961; they completed an optimism assessment in 1986 and mortality status was tracked through 2016. The cohorts used different measures of optimism, which prior work has demonstrated to be correlated (ref. 22; see *SI Appendix*, section S5 for details). We operationalized optimism as a continuous variable using z scores (standardized against sample-specific mean and SD) and also as a categorical variable. In NHS, we created quartiles of optimism scores, and we used quintiles for NAS as the NAS measure has more items and a broader scoring range.

Descriptive statistics by optimism categories in each cohort are presented in *SI Appendix*, Table S1. At baseline for these optimism analyses, NHS and NAS participants were on average 70 and 62 y old, respectively, were predominantly white, and were married. Qualitatively, women with higher levels of optimism were less likely to have an associate/registered nurse degree (compared to bachelor's, master's, or doctoral degrees), and less likely to report some health conditions, especially depression and type 2 diabetes. Men with higher levels of optimism had higher levels of education and family income; they were less likely to report depressive symptoms and have type 2 diabetes, and reported less alcohol use, and somewhat lower body mass index (BMI). Both men and women with higher optimism were more likely to engage in physical activity. While many variables in *SI Appendix*, Table S1 showed statistically significant differences across optimism categories, especially for NHS, primarily due to the large sample size, we focused on the magnitude of differences rather than strictly on statistical significance in interpreting findings.

We used accelerated failure time (AFT) models to test whether higher baseline levels of optimism were associated with greater longevity, as indicated by a longer life span. During the 10- and 30-y follow-up periods for NHS and NAS, 13% of the 69,744 women and 71% of the 1,429 men died, respectively. In NHS, higher levels of optimism were associated with extended life span in all models (Table 1, NHS; P trend ≤ 0.0001). For example, in a model adjusted for demographics, baseline health conditions, and depression, women in the highest versus lowest quartile of optimism had a life span 14.9% longer (95% confidence interval [CI]: 11.9%, 18.0%). To contextualize the magnitude of these estimates, in this model, never having been diagnosed with type 2 diabetes was associated with 17.0% (95% CI: 14.4%, 19.6%) longer life span and never having been diagnosed with myocardial infarction was associated with 18.0% (95% CI: 14.7%, 21.4%) longer life span. After additionally adjusting for health behaviors, the associations were substantially attenuated but remained statistically significant. For example, in the fully adjusted models, the highest versus lowest quartile of optimism was associated with an 8.7% (95% CI: 5.8%, 11.6%) longer life span. While it is possible that health behaviors are confounders in this association, such behaviors may also lie on the pathway linking optimism to longevity (23).

For men in NAS, higher baseline optimism levels were similarly related to longer life span (Table 1, NAS; P trend = 0.002). After adjusting for demographics, baseline health conditions, and depression, compared to the least optimistic men, those in the highest quintile had 10.9% (95% CI: 1.3%, 21.5%) longer life span. As a point of reference, in this model, never having been diagnosed with type 2 diabetes was associated with a 13.1% (95% CI: 2.7%, 22.5%) longer life span, and never having been diagnosed with heart disease was associated with 16.6% (95% CI: 10.4%, 22.4%) longer life span. After further adjusting for health behaviors, the association between higher levels of optimism and longer life span remained significant but was attenuated, similar to findings in women; life span was 9.8% longer (95% CI: 0.3%, 20.3%) in the top versus bottom quintile of optimism.

In further analyses using logistic regression models restricted to individuals who had the potential to reach age 85 by the end of mortality follow-up for each cohort, we assessed whether higher optimism levels were associated with greater odds of achieving exceptional longevity. In NHS, of the 13,045 women born early

Table 1. Percent differences in life span associated with optimism in NHS, 2004–2014 (n = 69,744), and NAS, 1986–2016 (n = 1,429)

	Optimism level (Q1 = least optimistic)											
	Q1		Q2		Q3		Q4		Q5		Continuous	
	% difference		%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
NHS (Q = quartile)												
DM	0.0	Ref.	9.6	7.5, 11.9	16.2	13.6, 19.0	18.6	15.4, 21.8	—	—	7.6	6.7, 8.5
DM + HC	0.0	Ref.	7.8	5.7, 10.0	13.3	10.7, 15.9	14.9	11.9, 18.0	—	—	6.1	5.4, 7.0
DM + HC + HB	0.0	Ref.	4.2	2.2, 6.3	7.8	5.3, 10.3	8.7	5.8, 11.6	—	—	3.5	2.6, 4.3
NAS (Q = quintile)												
DM	0.0	Ref.	6.5	−2.2, 15.9	8.7	−0.2, 18.3	11.5	2.3, 21.5	14.0	4.5, 24.4	4.5	1.6, 7.3
DM + HC	0.0	Ref.	4.6	−4.3, 14.3	6.6	−2.5, 16.5	8.3	−1.0, 18.5	10.9	1.3, 21.5	3.5	0.5, 6.6
DM + HC + HB	0.0	Ref.	5.2	−3.6, 14.9	7.7	−1.5, 17.7	6.5	−2.7, 16.6	9.8	0.3, 20.3	2.9	−0.1, 6.0

Notes: CI, confidence interval; DM, demographics model; HB, health behaviors; HC, health conditions; Ref., reference. Optimism was assessed with the LOT-R in NHS and PSM-R in NAS. For both cohorts, higher continuous scores represent higher levels of optimism. For NHS, the demographics model includes baseline age, race, marital status, education, husband's education, and father's occupation. Health conditions include high cholesterol, hypertension, type 2 diabetes, myocardial infarction, stroke, cancer, and depression at baseline. Health behaviors include smoking status, physical activity, alcohol consumption, screening, BMI, and diet. For NAS, the demographics model includes baseline age, being white, being married, education, family income, and father's occupation. Health conditions include high cholesterol, hypertension, type 2 diabetes, heart disease, stroke, cancer, and depression at baseline. Health behaviors include smoking status, alcohol use, physical activity, fruit and vegetable intake, BMI, and physician visit in the past 3 y assessed at baseline.

enough to be eligible for these analyses, 86% survived to age 85 or beyond. Higher optimism was associated with greater odds of achieving exceptional longevity, with a positive trend evident across optimism levels (Table 2, NHS; P trend < 0.01). After adjusting for demographics, baseline health conditions and depression, compared to women in the lowest quartile, the odds ratios (ORs) for exceptional longevity for women with higher optimism levels ranged from 1.2 (95% CI: 1.1, 1.3) in the second lowest quartile to 1.5 (95% CI: 1.2, 1.7) in the highest quartile. After further adjusting for baseline health behaviors, estimates were attenuated but remained statistically significant.

In NAS, of the 1,117 men born early enough to be eligible for these analyses, 56% survived to age 85 or beyond. Higher optimism was also associated with greater odds of achieving exceptional longevity (Table 2, NAS; P trend < 0.01). Adjusting for demographics, baseline health conditions, and depression, compared to men in the least optimistic quintile, ORs for exceptional longevity were larger for men with higher optimism levels, ranging from 1.5 (95% CI: 1.0, 2.3) in the second lowest quintile to 1.7 (95% CI: 1.1, 2.6) in the highest quintile (both values of $P < 0.05$). After adding health behaviors to the model, the 2 highest optimism quintiles remained significantly related to higher odds of achieving exceptional longevity.

We conducted several sensitivity analyses. First, to address potential concerns regarding residual confounding between optimism and baseline health conditions, we repeated the AFT and logistic regression analyses after excluding respondents with major chronic diseases at baseline (N excluded: 15,952 in NHS, 294 in NAS). Results remained comparable to those reported above (*SI Appendix*, Tables S2 and S3). However, fewer associations reached statistical significance, likely due to the reduced sample sizes. We also tested possible confounding by other psychosocial assets that may promote longevity. In particular, social integration, as indicated by the presence of ties to multiple social networks (e.g., marriage, friendship), is correlated with optimism (24), has consistently predicted survival across multiple studies, and has a strong association with survival (14). When we included social integration in the AFT analyses, the associations of optimism to longer life span were somewhat attenuated but remained statistically significant in both cohorts (*SI Appendix*, Table S4). We did not also consider logistic regression models of survival to age 85 with the additional social integration covariate; NHS women who had the potential to reach age 85 represented 19% of the overall population, and as they were older at baseline, as expected, had more missing data. Thus, adding social integration variables to models would further reduce the eligible sample, yielding concern regarding the validity of analyses with this subset.

Discussion

In 2 long-term, longitudinal cohorts of women and men, higher optimism levels were associated with longer life span and higher odds of achieving exceptional longevity. These associations were maintained after adjusting for demographics and baseline health conditions. Accounting for baseline health behaviors that could confound the association or potentially also lie on the pathway between optimism and longevity attenuated the associations, but findings remained significant and comparable in magnitude between men and women. A unique feature of this study is the focus on exceptional longevity. While prior studies have reported that optimism may reduce risk of premature death in mid- and later life, the current findings suggest that optimism promotes substantially longer life span. As longer life span appears to accompany longer health span (3), our findings have implications for understanding psychosocial factors that promote healthy and resilient aging.

Our findings are consistent with and extend those from our own (4) and other studies (9, 25) reporting associations between higher optimism and lower all-cause mortality risk. In 941 older Dutch adults followed for a decade, Giltay et al. (25) reported optimism was more strongly related to reduced risk of premature mortality in men (42 to 53% risk reduction in multivariate models) than women (9 to 31% risk reduction), although there was lower statistical power to detect an association in women than men. The present study included larger samples of women (N = 69,744) and men (N = 1,429), and a lengthier follow-up for men (30 y). We observed similar effect sizes between sexes and findings were robust across these 2 independent cohorts.

Other strengths of our study include the ability to consider a broad set of covariates related to both optimism and longevity. We

Table 2. Odds ratios for the association of optimism with survival to age 85+, NHS (n = 13,045) and NAS (n = 1,117)

	Optimism level (Q1 = least optimistic)											
	Q1		Q2		Q3		Q4		Q5		Continuous	
	OR	—	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
NHS (Q = quartile)												
DM	1.0	Ref.	1.2	1.1, 1.4	1.6	1.3, 1.8	1.6	1.3, 1.9	—	—	1.2	1.2, 1.3
DM + HC	1.0	Ref.	1.2	1.1, 1.3	1.5	1.3, 1.7	1.5	1.2, 1.7	—	—	1.2	1.1, 1.3
DM + HC + HB	1.0	Ref.	1.1	1.0, 1.2	1.3	1.1, 1.5	1.2	1.0, 1.5	—	—	1.1	1.1, 1.2
NAS (Q = quintile)												
DM	1.0	Ref.	1.5	1.0, 2.2	1.5	1.0, 2.2	1.7	1.2, 2.5	1.8	1.2, 2.7	1.2	1.1, 1.4
DM + HC	1.0	Ref.	1.5	1.0, 2.3	1.5	1.0, 2.2	1.7	1.1, 2.5	1.7	1.1, 2.6	1.2	1.0, 1.3
DM + HC + HB	1.0	Ref.	1.5	1.0, 2.2	1.4	0.9, 2.1	1.5	1.0, 2.3	1.6	1.0, 2.4	1.1	1.0, 1.3

Notes: CI, confidence interval; DM, demographics model; HB, health behaviors; HC, health conditions; Ref., reference. Optimism was assessed with the LOT-R in NHS and PSM-R in NAS. For both cohorts, higher continuous scores represent higher levels of optimism. For NHS, the demographics model includes baseline age, race, marital status, education, husband's education, and father's occupation. Health conditions include high cholesterol, hypertension, type 2 diabetes, myocardial infarction, stroke, cancer, and depression at baseline. Health behaviors include smoking status, physical activity, alcohol consumption, screening, BMI, and diet. For NAS, the demographics model includes baseline age, being white, being married, education, family income, and father's occupation. Health conditions include high cholesterol, hypertension, type 2 diabetes, heart disease, stroke, cancer, and depression at baseline. Health behaviors include smoking status, alcohol use, physical activity, fruit and vegetable intake, BMI, and physician visit in the past 3 y assessed at baseline.

did not find that existing health conditions introduced meaningful confounding in the relation of optimism to life span. In analyses considering both life span and likelihood of achieving exceptional longevity, associations with optimism were largely maintained after adjusting for numerous physical health conditions at baseline, including high cholesterol, hypertension, type 2 diabetes, heart disease, stroke, and cancer. Furthermore, associations withstood adjustment for depression, suggesting optimism does not simply signal the absence of psychological distress and related risks, but rather may confer independent benefits for longevity.

Given studies documenting strong linkages between optimism and greater engagement in healthy behaviors, health behaviors may provide a mechanism linking optimism to longevity (26). In the present study, we note that the estimates for optimism were consistently attenuated when adjusted for a large panel of health behaviors at baseline, including smoking, alcohol use, physical activity, diet, BMI, and primary care visits. Optimistic individuals tend to have goals and the confidence to reach them; thus, optimism may foster health-promoting habits and bolster resistance of unhealthy impulses through greater engagement with one's goals, more efficacious problem-solving, and adjustment of goals when they become unattainable (11).

In addition to promoting healthier behaviors, there are other potential explanations for the associations of optimism to longer life span. Considering psychosocial pathways, more optimistic individuals may experience less extreme emotional reactivity to, and faster recovery from, acute stressors (27). When faced with difficulties, more optimistic individuals appear to have better capacity to regulate emotions through cognitive routes, such as reframing situations as challenges rather than threats, or through behavioral mechanisms, such as resisting immediate rewards in service of longer-term goals (11, 28). Considering biological pathways, higher levels of optimism have been linked to healthier biomarker profiles in the cardiovascular (7), metabolic (29), immune (30), and pulmonary (10) systems. Given research identifying an increasing number of psychosocial assets for good health, an issue to consider is unique vs. shared variance among these attributes. In sensitivity analyses, we found that adjusting for social integration somewhat attenuated but did not fully account for the association of optimism to extended life span, providing support for some independent effects. However, additional work might consider potential additive effects among psychosocial assets and whether there are critical health-beneficial components shared across assets.

Several limitations should be considered. First, both cohorts were mostly white and had higher socioeconomic status than the general population, therefore findings may not generalize to racial/ethnic minorities and more socioeconomically disadvantaged populations. Other studies in US populations have generally found that individuals with higher education, income, and occupational status have higher optimism levels (31), although racial and ethnic differences are less clear (9, 31) and may be modified by other sociodemographic factors such as household income (32). However, few studies have examined these relationships. Most importantly, associations of optimism with health outcomes persist across diverse groups, although evidence is also limited (9, 33). Taken together, this work suggests that while some groups may differentially attain higher optimism levels, the apparent health benefits are similar across groups. Second, we examined associations among middle-aged and older adults in both cohorts. It is unclear how earlier-life processes might shape both optimism and likelihood of exceptional longevity. However, optimism appears to be highly stable in adulthood (e.g., 5-y correlation = 0.87 in NAS); thus, aging-related changes in optimism are unlikely to have a strong impact on our findings. Third, reverse causality is possible, whereby less healthy or already-ill individuals are less optimistic at study baseline, and therefore less likely to achieve exceptional longevity. However, our primary analyses excluded those who died early in the follow-up, and the pattern of findings remained stable in sensitivity analyses that excluded individuals with major chronic diseases at baseline.

Together with other work, our findings suggest optimism serves as a psychological resource that promotes health and longevity. If so, then optimism offers a valuable target for interventions seeking to promote health by fostering psychological resources. This approach would be somewhat different from more mainstream approaches that often aim to mitigate or repair psychological deficits. A recent meta-analysis of 29 studies showed that relatively brief interventions can enhance optimism (34), although this work has not followed participants over the long term. Interventions range from brief writing exercises and meditation to more intensive cognitive-behavioral therapy practices. Recent work has evaluated the feasibility of conducting 8-wk interventions to increase optimism and other facets of psychological well-being in cardiac patients (35). Future research should address whether improvements in optimism will translate into behavioral or health benefits in the short or long term.

In conclusion, we found higher optimism levels were associated with longer life span and greater likelihood of achieving exceptional longevity. Importantly, these associations were replicated across 2 independent cohorts and remarkably similar in magnitude in men and women, after adjusting for potential confounders and possible intermediate variables. Given research showing that increasing health span often accompanies increasing life span, our findings suggest optimism may be an important psychosocial resource in promoting healthy aging (33). Such findings add to the arsenal of potentially modifiable factors that should be targeted to improve population health and longevity.

Materials and Methods

Study Populations. We used data from 2 long-running longitudinal cohorts, 1 composed solely of women and 1, solely of men.

NHS. The NHS cohort began in 1976 with 121,700 female registered nurses, aged 30 to 55 y. Since 1976, participants have completed biennial questionnaires assessing health, diet, lifestyle, and psychosocial factors. Follow-up throughout the study has exceeded 90%. The sample for the current study included women who completed the optimism measure, the Life Orientation Test–Revised (LOT-R) (36) in 2004, the baseline for these analyses. Of these 71,432 women, 1,400 died within the first 2 y of follow-up and were excluded from analyses to mitigate the possibility that imminent health decline affected their reports of optimism. Another 288 women were excluded due to having less than 2 y of follow-up data. Mortality follow-up was complete through 2014. The mean age of the NHS analytic sample at baseline was 69.9 y (SD, 6.9; range, 58 to 86). Women who were included vs. excluded from the study population due to failure to complete the optimism measure (n = 33,795) were similar in age (69.9 vs. 71.1 y), BMI (26.2 vs. 26.7), and smoking prevalence (8% vs. 8% current smokers, 48% vs. 47% past smokers).

NAS. NAS is a longitudinal investigation of normative and pathological aging processes in 2,280 initially healthy men aged 21 to 80 y when enrolled at the VA Boston Outpatient Clinic between 1961 and 1970 (37). Over 6,000 men were screened for the absence of major physical and mental illnesses, and for geographic stability, defined as kinship ties in the Boston area and stated intentions to remain local. Optimism was assessed using items from the Minnesota Multiphasic Personality Inventory-2 (MMPI-2) (38), administered as part of a mail survey to all active cohort members in 1986 (response, 82.4%; for details, see ref. 6), which serves as the baseline for the current analyses. Men who completed this optimism assessment were eligible for the current study. Of the 1,472 respondents, 24 were excluded due to missing more than 5% of the items in the optimism measure, and another 19 were excluded due to death within the first year of follow-up, yielding an analytic sample of 1,429 men. Mortality data through 2016 were used. The mean age of the NAS analytic sample at baseline was 61.6 y (SD, 8.3; range, 41 to 90). Men who were included vs. excluded from the study due to failing to complete ≥95% of items in the optimism measure were more likely to be heavy drinkers. However, the 2 groups did not differ on baseline demographics or health conditions.

Optimism Assessment.

NHS. Optimism was assessed in 2004 via the LOT-R, previously demonstrated to have good discriminant and convergent validity and good reliability (36); internal consistency reliability was α = 0.79 in our sample. Participants

reported the degree to which they agreed with 6 statements, with responses on a 5-point Likert scale. After reverse-coding negatively worded items, items were summed to create a composite score ranging from 0 to 24, with higher scores indicating greater optimism. If a participant missed any question, their overall score was marked as missing. Because optimism is best characterized by both endorsing positively worded items and rejecting negatively worded items, we followed recent recommendations to use the 6-item composite rather than 3-item subscales sometimes used (39).

NAS. Optimism was assessed in 1986 via the Revised Optimism–Pessimism Scale (PSM-R) (40). The PSM-R is based on 263 MMPI-2 items and measures explanatory style on a bipolar continuum from optimistic to pessimistic. We generated maximum-likelihood estimates of missing items on the PSM-R (constrained to fewer than 5% of items by study design) based on participants' available PSM-R data from 2 NAS MMPI-2 administrations in 1986 and 1991, although most PSM-R data came from 1986. A total PSM-R score was computed from the individual items (40); total scores were reverse-coded such that high scores indicate more optimism and low scores indicate more pessimism. The PSM-R has good internal consistency (Kuder–Richardson 20 = 0.88) and stability over a 5-y period in NAS ($r = 0.87$, $P < 0.001$). Prior work has demonstrated moderate correlations between the LOT and the PSM-R (6, 41). See *SI Appendix*, section S5 for more detail on these optimism measures.

Mortality Assessment. We considered 2 outcomes related to longevity: average increases in life span and exceptional longevity, defined as survival to age 85 or older.

NHS. Deaths are identified through various sources, including report by participants' families and postal authorities, and searches of the National Death Index (NDI). A test of death ascertainment from the NDI found that 98% of deaths were identified (42). Date of death is ascertained from systematic searches of state vital records and the NDI, with supplementation by reports from family members. In the current study, deaths were identified through June 1, 2014.

NAS. Vital status information was collected using several methods, including routine searches of Social Security Administration (Death Master File) and VA records; and notification of participant deaths from next-of-kin or postal authorities triggered by regular mailings to participants. We considered all-cause mortality between the optimism assessment in 1986 and December 31, 2016.

Covariate Assessment.

NHS. Demographic variables were assessed on the biennial questionnaires, and we used data from the 2004 questionnaire, when optimism was assessed. These included age (continuous), race (white, black, Asian, or other), marital status (married, widowed, divorced/separated/single), education level (registered nurse/associate's degree, bachelor's degree, or master's/doctoral degree), husband's education level (less than high school, some high school, high school graduate, college graduate, or graduate degree), and father's occupation when the participant was 16 y old (craftsman/laborer/farmer, clerical/sales/service, or professional/managerial).

Depression status (yes vs. no) was assessed in 2004 on the biennial questionnaire. Participants were considered depressed if they reported a physician diagnosis of depression, regular antidepressant use, or depressive symptoms per the Center for Epidemiologic Study Depression Scale–Revised, whereby a score ≥10 was considered indicative of depressive symptoms (43). History (yes vs. no) of major chronic conditions, including high cholesterol, high blood pressure, type 2 diabetes, cancer, stroke, and myocardial infarction, was also reported on the biennial questionnaires, and we considered prevalence as of 2004. Social integration was assessed in 2004 with the widely used and well-validated Berkman–Syme Social Network Index (44). Total score (0 to 4) reflects the number of the following characteristics endorsed: married, had more than 6 close friends or relatives, attended weekly religious group activities, and attended weekly community activities.

Health behaviors included smoking history, physical activity, alcohol use, diet quality, physical examination for screening purposes, and BMI; these items were all assessed on the 2004 questionnaire, except alcohol use and diet quality, which were assessed in 2006. Self-reported smoking history was classified as current, former, or never. Self-reported physical activity, modeled as a categorical variable according to the number of metabolic equivalent (MET) hours per week (<3.0, 3.0 to 8.9, 9.0 to 17.9, 18.0 to 26.9, or ≥27.0 METs/wk), was calculated across 10 common activities (e.g., running, walking; ref. 45). Alcohol use and diet quality were assessed via a food frequency questionnaire. Alcohol was modeled as a categorical variable classifying the average number of grams of alcohol per day (none, 1 to 14 g, or 15+ g). Diet quality was operationalized using the Alternative Health Eating Index (46), which produces a continuous score ranging from 0 to 110 (higher scores indicate healthier diet). The overall score is based on 11 components such as high intake of fruits, vegetables, and cereal fiber, and low consumption of red meat, saturated fat, and trans fat. Medical screening (yes vs. no) was assessed with a question that asked whether one had undergone a physical examination for screening purposes in the previous 2 y. BMI was calculated using participants' self-reported height and weight, validated previously in an NHS substudy (47).

NAS. Demographic variables were assessed on questionnaires at NAS entry in 1961 to 1970: race (white vs. other), paternal occupation (unskilled, semiskilled, skilled and foreman, white collar, semiprofessional, professional/managerial/proprietary); and in 1986: age (continuous), marital status (married vs. other), education (years), total family income (0 = under $3,000, 1 = $3,000–$3,999, to 16 = $75,000+).

Depression was assessed with the Symptom Checklist 90–Revised (48) administered as part of a mail survey in 1985. Men with a *T* score of 70 or above were coded as being depressed, and as not depressed otherwise. Health conditions were assessed at NAS physical examinations occurring every 3 to 5 y, at which participants' medical histories were updated, and measures of various biochemical values (e.g., serum cholesterol) were obtained. Health conditions include high cholesterol, hypertension, type 2 diabetes, coronary heart disease, stroke, and cancer, which were coded as positive if present by study baseline (1986), as determined by NAS physicians. Social integration was assessed concurrently with depression in the 1985, using an index that closely resembles the NHS social integration measure. Total score (0 to 3) reflects the number of the following characteristics endorsed: married, had 6 or more close friends or relatives, and participated in community or volunteer activities at least some of the time.

For health behaviors, BMI and smoking status (current, former, never) were assessed by study staff during examinations, taken from an examination closest in time and within 1.5 y of the optimism assessment. Alcohol use (none to moderate, former, and heavy or problematic drinking) was assessed with a questionnaire item administered concurrently with optimism in 1986. Average daily intake of fruits and vegetables was assessed via the Food Frequency Questionnaire (FFQ) (adapted from the questionnaire used in NHS) and scored using the approach described by Park et al. (49). Physical activity was assessed in a supplemental questionnaire to the FFQ. Items query the average time spent per week on 10 activities in the past year; responses were coded to indicate the average kilocalories expended on exercise per week. Since 1997, NAS incorporated the FFQ and its supplemental questionnaire into a battery of questionnaires mailed to participants before their examination visit and checked for completeness at the visit. We included FFQ and physical activity data from an examination closest in time and within 3 y of the optimism assessment. Timing of the most recent physician visit (aside from NAS examinations) was measured with a questionnaire item administered concurrently with optimism items; response was dichotomized into having a visit within the past 3 y vs. longer.

Statistical Analysis. AFT models were used to test the hypothesis that higher levels of baseline optimism would be associated with greater longevity. An AFT model predicting the survival time *T*, defined as number of years lived (i.e., age at death) for individual *i*, was specified as follows:

$$\log T_i = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_i x_{ik} + \sigma\varepsilon_i,$$

where $x_{i1}, x_{i2}, \ldots x_{ik}$ were the values of *k* covariates for individual *i*, ε_i was the error variance of predicted log-survival time, and σ was the scaling parameter that specified the distribution of the error term. When the transformation $100(e^{\beta} - 1)$ is applied to the regression coefficient β for an independent variable *x*, the result can be interpreted as the percent increase in the expected survival time for each 1-unit increase in *x*.

Logistic regression was used to test the hypothesis that higher levels of baseline optimism would be associated with greater odds of achieving exceptional longevity. Logistic regression models were restricted to individuals who had the potential to reach age 85 by the right-censoring date of each study (NHS: June 1, 2014; NAS: December 31, 2016.)

For both AFT and logistic regression analyses, we evaluated 3 models. Model 1 adjusted for demographics as potential confounders. Model 2 added baseline health conditions and depression as potential confounders that could help explain the association between optimism and longevity. Model 3 further considered baseline health behaviors as potential confounders and/or intermediate variables. For each model, we considered optimism both as a continuous variable and a categorical variable (i.e., quartiles in NHS, quintiles in NAS).

Two sets of sensitivity analysis were conducted. First, we assessed whether the observed associations in AFT and logistic models persisted after excluding

participants with chronic diseases at baseline. Second, in light of research on a growing array of psychosocial assets that can promote longevity, we evaluated whether relations of optimism to long life span were independent of social integration in AFT analyses. We did not incorporate social integration as a covariate in logistic models because of the reduced analytic sample for NHS and concerns about the validity of analyses with this subset.

ACKNOWLEDGMENTS. This work was supported by grants from the NIH (R01-AG053273, R01-AG018436, K08-AG048221, UL1-TR001430, R00-CA201542, K99-AG055696, and UM1-CA186107), a Senior Research Career Scientist Award from the Clinical Science Research and Development Service, US Department of Veterans Affairs (VA) to A.S., and a postdoctoral fellowship from Fonds de Recherche en Santé–Quebec to C.T.-F. The VA NAS is a research component of the Massachusetts Veterans Epidemiology Research and Information Center and is supported by the VA Cooperative Studies Program/Epidemiological Research Centers. The views expressed in this paper are those of the authors and do not necessarily represent the views of the US Department of Veterans Affairs or other support institutions.

1. M. Revelas *et al*., Review and meta-analysis of genetic polymorphisms associated with exceptional human longevity. *Mech. Ageing Dev.* **175**, 24–34 (2018).
2. V. D. Longo *et al*., Interventions to slow aging in humans: Are we ready? *Aging Cell* **14**, 497–510 (2015).
3. C. López-Otín, M. A. Blasco, L. Partridge, M. Serrano, G. Kroemer, The hallmarks of aging. *Cell* **153**, 1194–1217 (2013).
4. E. S. Kim *et al*., Optimism and cause-specific mortality: A prospective cohort study. *Am. J. Epidemiol.* **185**, 21–29 (2017).
5. E. S. Kim, N. Park, C. Peterson, Dispositional optimism protects older adults from stroke: The Health and Retirement Study. *Stroke* **42**, 2855–2859 (2011).
6. L. D. Kubzansky, D. Sparrow, P. Vokonas, I. Kawachi, Is the glass half empty or half full? A prospective study of optimism and coronary heart disease in the normative aging study. *Psychosom. Med.* **63**, 910–916 (2001).
7. K. A. Matthews, K. Räikkönen, K. Sutton-Tyrrell, L. H. Kuller, Optimistic attitudes protect against progression of carotid atherosclerosis in healthy middle-aged women. *Psychosom. Med.* **66**, 640–644 (2004).
8. H. N. Rasmussen, M. F. Scheier, J. B. Greenhouse, Optimism and physical health: A meta-analytic review. *Ann. Behav. Med.* **37**, 239–256 (2009).
9. H. A. Tindle *et al*., Optimism, cynical hostility, and incident coronary heart disease and mortality in the Women's Health Initiative. *Circulation* **120**, 656–662 (2009).
10. L. D. Kubzansky *et al*., Breathing easy: A prospective study of optimism and pulmonary function in the normative aging study. *Ann. Behav. Med.* **24**, 345–353 (2002).
11. L. Kubzansky, J. Boehm, S. Segerstrom, Positive psychological functioning and the biology of health. *Soc. Personal. Psychol. Compass* **9**, 645–660 (2015).
12. J. K. Boehm, L. D. Kubzansky, The heart's content: The association between positive psychological well-being and cardiovascular health. *Psychol. Bull.* **138**, 655–691 (2012).
13. Y. Chida, A. Steptoe, Positive psychological well-being and mortality: A quantitative review of prospective observational studies. *Psychosom. Med.* **70**, 741–756 (2008).
14. J. Holt-Lunstad, T. B. Smith, J. B. Layton, Social relationships and mortality risk: A meta-analytic review. *PLoS Med.* **7**, e1000316 (2010).
15. C. S. Carver, M. F. Scheier, Dispositional optimism. *Trends Cogn. Sci.* **18**, 293–299 (2014).
16. Y. M. C. Meevissen, M. L. Peters, H. J. E. M. Alberts, Become more optimistic by imagining a best possible self: Effects of a two week intervention. *J. Behav. Ther. Exp. Psychiatry* **42**, 371–378 (2011).
17. M. L. Peters, I. K. Flink, K. Boersma, S. J. Linton, Manipulating optimism: Can imagining a best possible self be used to increase positive future expectancies? *J. Posit. Psychol.* **5**, 204–211 (2010).
18. J. vB Hjelmborg *et al*., Genetic influence on human lifespan and longevity. *Hum. Genet.* **119**, 312–321 (2006).
19. T. Perls, L. M. Kunkel, A. A. Puca, The genetics of exceptional human longevity. *J. Am. Geriatr. Soc.* **50**, 359–368 (2002).
20. L. B. Yates, L. Djoussé, T. Kurth, J. E. Buring, J. M. Gaziano, Exceptional longevity in men: Modifiable factors associated with survival and function to age 90 years. *Arch. Intern. Med.* **168**, 284–290 (2008).
21. A. B. Newman, J. M. Murabito, The epidemiology of longevity and exceptional survival. *Epidemiol. Rev.* **35**, 181–197 (2013).
22. C. Peterson, R. S. Vaidya, Explanatory style, expectations and depressive symptoms. *Pers. Individ. Dif.* **31**, 1217–1223 (2001).
23. M. F. Scheier, C. S. Carver, Dispositional optimism and physical health: A long look back, a quick look forward. *Am. Psychol.* **73**, 1082–1094 (2018).
24. I. Brissette, M. F. Scheier, C. S. Carver, The role of optimism in social network development, coping, and psychological adjustment during a life transition. *J. Pers. Soc. Psychol.* **82**, 102–111 (2002).
25. E. J. Giltay, J. M. Geleijnse, F. G. Zitman, T. Hoekstra, E. G. Schouten, Dispositional optimism and all-cause and cardiovascular mortality in a prospective cohort of elderly Dutch men and women. *Arch. Gen. Psychiatry* **61**, 1126–1135 (2004).
26. J. K. Boehm *et al*., Is optimism associated with healthier cardiovascular-related behavior? Meta-analyses of 3 health behaviors. *Circ. Res.* **122**, 1119–1134 (2018).
27. D. M. Almeida, J. R. Piazza, R. S. Stawaski, L. C. Klein, "The speedometer of life: Stress, health and aging" in *Handbook of the Psychology of Aging*, K. W. Schaie, S. Willis, Eds. (Academic Press, San Diego, ed. 7, 2011), pp. 191–206.
28. H. N. Rasmussen, C. Wrosch, M. F. Scheier, C. S. Carver, Self-regulation processes and health: The importance of optimism and goal adjustment. *J. Pers.* **74**, 1721–1747 (2006).
29. J. K. Boehm, D. R. Williams, E. B. Rimm, C. Ryff, L. D. Kubzansky, Relation between optimism and lipids in midlife. *Am. J. Cardiol.* **111**, 1425–1431 (2013).
30. A. Ikeda *et al*., Optimism in relation to inflammation and endothelial dysfunction in older men: The VA normative aging study. *Psychosom. Med.* **73**, 664–671 (2011).
31. J. K. Boehm, Y. Chen, D. R. Williams, C. Ryff, L. D. Kubzansky, Unequally distributed psychological assets: Are there social disparities in optimism, life satisfaction, and positive affect? *PLoS One* **10**, e0118066 (2015).
32. C. Graham, S. Pinto, Unequal hopes and lives in the USA: Optimism, race, place, and premature mortality. *J. Popul. Econ.* **32**, 665–733 (2019).
33. P. James *et al*., Optimism and healthy aging in women. *Am. J. Prev. Med.* **56**, 116–124 (2019).
34. J. M. Malouff, N. S. Schutte, Can psychological interventions increase optimism? A meta-analysis. *J. Posit. Psychol.* **12**, 594–604 (2017).
35. N. Mohammadi *et al*., A randomized trial of an optimism training intervention in patients with heart disease. *Gen. Hosp. Psychiatry* **51**, 46–53 (2018).
36. M. F. Scheier, C. S. Carver, M. W. Bridges, Distinguishing optimism from neuroticism (and trait anxiety, self-mastery, and self-esteem): A reevaluation of the Life Orientation Test. *J. Pers. Soc. Psychol.* **67**, 1063–1078 (1994).
37. A. Spiro, III, R. Bossé, "The Normative Aging Study" in *The Encyclopedia of Aging*, G. L. Maddox, Ed. (Springer, New York, 2001), pp. 744–746.
38. J. N. Butcher, W. G. Dahlstrom, J. R. Graham, A. M. Tellegen, B. Kaemmer, *Minnesota Multiphasic Personality Inventory-2 (MMPI-2): Manual for Administration and Scoring* (University of Minnesota Press, Minneapolis, 1989).
39. S. C. Segerstrom, D. R. Evans, T. A. Eisenlohr-Moul, Optimism and pessimism dimensions in the Life Orientation Test-Revised: Method and meaning. *J. Res. Pers.* **45**, 126–129 (2011).
40. M. Malinchoc, K. P. Offord, R. C. Colligan, PSM-R: Revised Optimism-Pessimism Scale for the MMPI-2 and MMPI. *J. Clin. Psychol.* **51**, 205–214 (1995).
41. M. F. Scheier, C. S. Carver, Dispositional optimism and physical well-being: The influence of generalized outcome expectancies on health. *J. Pers.* **55**, 169–210 (1987).
42. J. W. Rich-Edwards, K. A. Corsano, M. J. Stampfer, Test of the National Death Index and Equifax Nationwide Death Search. *Am. J. Epidemiol.* **140**, 1016–1019 (1994).
43. E. M. Andresen, J. A. Malmgren, W. B. Carter, D. L. Patrick, Screening for depression in well older adults: Evaluation of a short form of the CES-D (Center for Epidemiologic Studies Depression Scale). *Am. J. Prev. Med.* **10**, 77–84 (1994).
44. L. F. Berkman, S. L. Syme, Social networks, host resistance, and mortality: A nine-year follow-up study of Alameda County residents. *Am. J. Epidemiol.* **109**, 186–204 (1979).
45. S. Chasan-Taber *et al*., Reproducibility and validity of a self-administered physical activity questionnaire for male health professionals. *Epidemiology* **7**, 81–86 (1996).
46. S. E. Chiuve *et al*., Alternative dietary indices both strongly predict risk of chronic disease. *J. Nutr.* **142**, 1009–1018 (2012).
47. E. B. Rimm *et al*., Validity of self-reported waist and hip circumferences in men and women. *Epidemiology* **1**, 466–473 (1990).
48. L. R. Derogatis, *SCL-90-R. Administration, Scoring and Procedures Manual-I for the R(evised) Version and Other Instruments of the Psychopathology Rating Scale Series* (Johns Hopkins University School of Medicine, Baltimore, 1977).
49. S. K. Park *et al*., Fruit, vegetable, and fish consumption and heart rate variability: The Veterans Administration Normative Aging Study. *Am. J. Clin. Nutr.* **89**, 778–786 (2009).